Weaker when wet: The influence of water saturation on the rock-mass strength of the Permo-Triassic sandstones at the Soultz-sous-Forêts geothermal site (France)

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1 Introduction

The presence of aqueous fluids within the void space of rock—a combination of pores and cracks—is known to influence their short-term mechanical behaviour.

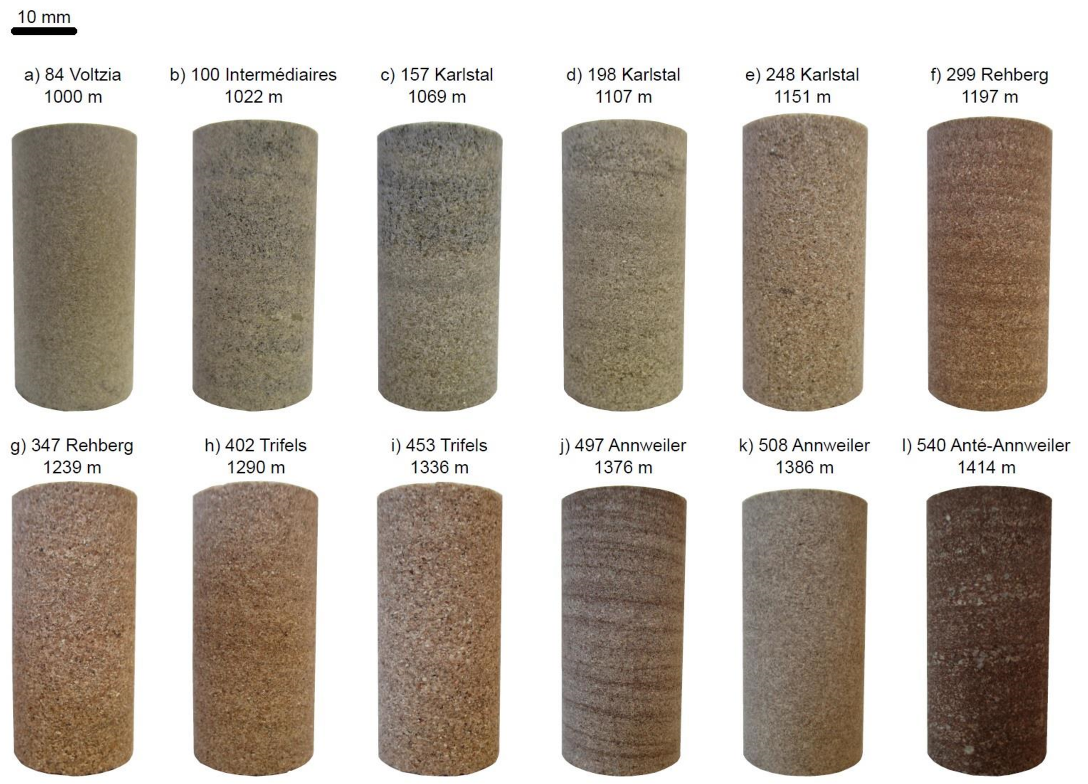
Therefore, laboratory deformation experiments performed on dry samples, the standard method to assess the strength of reservoir rock, may overestimate intact rock strength and rock mass strength asssessments provided by the generalised Hoek-Brown failure criterion.

We present here a systematic experimental study on the influence of water saturation on the strength of the Permo- Triassic sediments sampled from exploration well EPS-1 at the Soultz-sous-Forêts geothermal site (France). Future work will involve upscaling these strengths, using the generalised Hoek-Brown failure criterion, to provide "wet" and "dry" rock mass strengths of the Buntsandstein.

2 Experimental materials

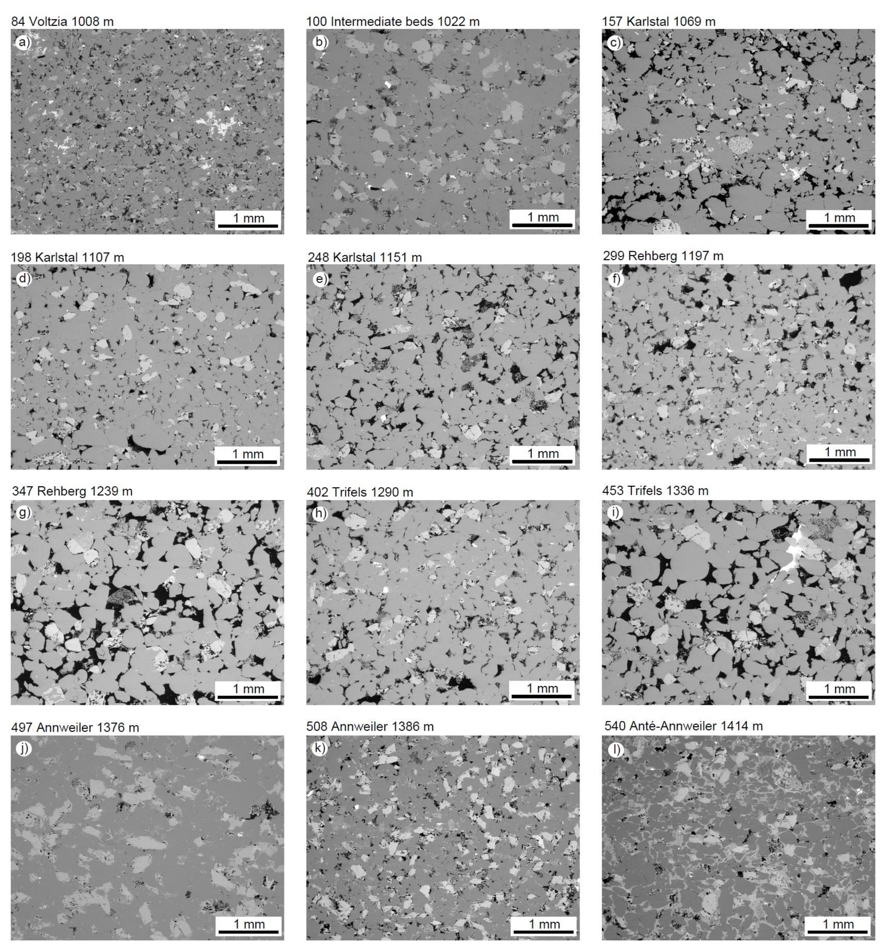
We sampled the EPS-1 borehole core at regular (~40-50 m) depth intervals (between 1008 to 1414 m). Twelve samples (i.e. depths) were selected, eleven from the Permo-Triassic Buntsandstein unit and one from the Permian unit sandwiched between the Buntsandstein and the Palaeozoic granitic basement.

Cylindrical samples (20 mm in diameter) were cored from each of the twelve borehole sandstones collected and were precision-ground to a nominal length of 40 mm (photographs are shown on the right).



These samples were cored perpendicular to bedding.

Scanning electron microscope images of each of the studied sandstones are shown below.



X-ray powder diffraction was performed on each of the twelve samples. These data attest to the presence of alteration minerals such as R3 illite-smectite.

Box number	84	100	157	198	248	299	347	402	453	497	508	540
Depth (m)	1008	1022	1069	1107	1151	1197	1239	1290	1336	1376	1386	1414
Stratigraphic unit	Voltzia	Intermédiaires	Karlstal	Karlstal	Karlstal	Rehberg	Rehberg	Trifels	Trifels	Annweiler	Annweiler	Anté-Annweiler
Quartz	74.5 ± 1.6	78.9 ± 1.7	89.2 ± 0.4	89.0 ± 1.1	90.7 ± 1.2	83.4 ± 2.6	87.8 ± 1.3	86.7 ± 1.6	82.3 ± 1.7	73.3 ± 3.0	70.6 ± 2.8	66.4 ± 4.0
Orthoclase	3.7 ± 1.9	5.6 ± 0.0	4.6 ± 1.1	3.2 ± 0.2	1.9 ± 0.1	1.7 ± 0.2	2.4 ± 0.0	3.0 ± 0.8	4.3 ± 0.6	4.8 ± 0.4	6.9 ± 1.1	4.4 ± 0.9
Microcline	9.3 ± 0.8	9.7 ± 0.5	4.0 ± 1.7	4.6 ± 0.0	4.5 ± 0.2	7.4 ± 0.5	5.9 ± 0.1	6.6 ± 0.3	9.4 ± 0.4	11.1 ± 0.6	13.8 ± 0.5	10.7 ± 0.7
Muscovite/Illite-Smectite	6.0 ± 2.9	5.0 ± 2.5	2.0 ± 0.8	3.2 ± 1.3	2.8 ± 1.3	7.3 ± 3.2	3.8 ± 1.5	3.5 ± 2.1	3.0 ± 1.8	7.8 ± 3.9	8.3 ± 4.5	13.1 ± 6.0
Dolomite	4.7 ± 0.1	1.0 ± 0.3	0.2 ± 0.1	-	-	-	-	-	0.8 ± 0.0	2.1 ± 0.0	-	4.2 ± 0.5
Siderite	1.9 ± 0.2	-	-	-	-	-	-	-	-	-	-	-
Hematite	-	-	-	-	0.2 ± 0.1	0.5 ± 0.1	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.1	0.9 ± 0.1	0.5 ± 0.1	1.4 ± 0.1

3 Experimental methods

Sample porosity was first measured using a helium pycnometer.

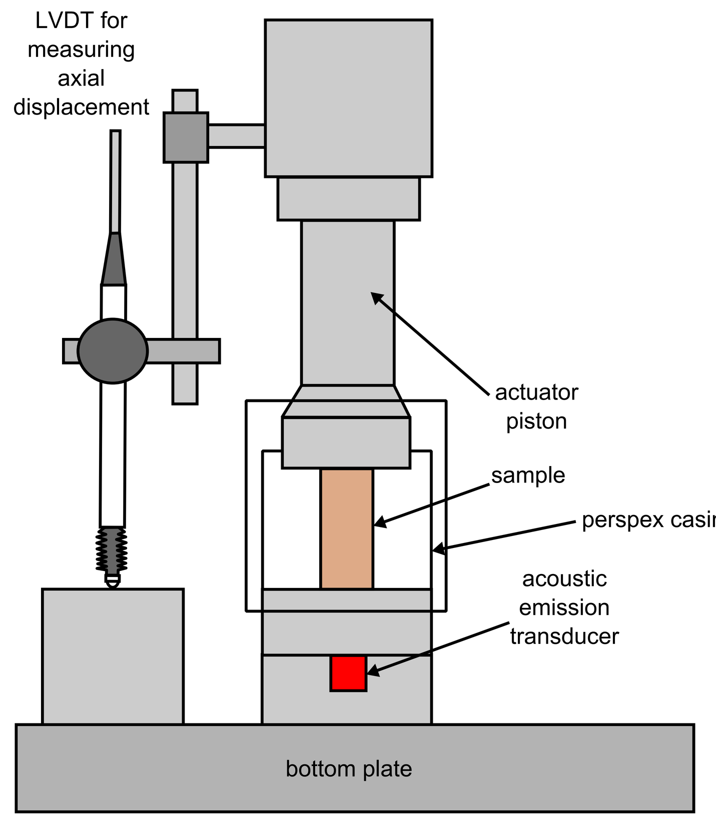
Samples were deformed in a uniaxial press.

Samples were deformed at a constant strain rate of 1 x 10^{-6} s^{-1} until failure.

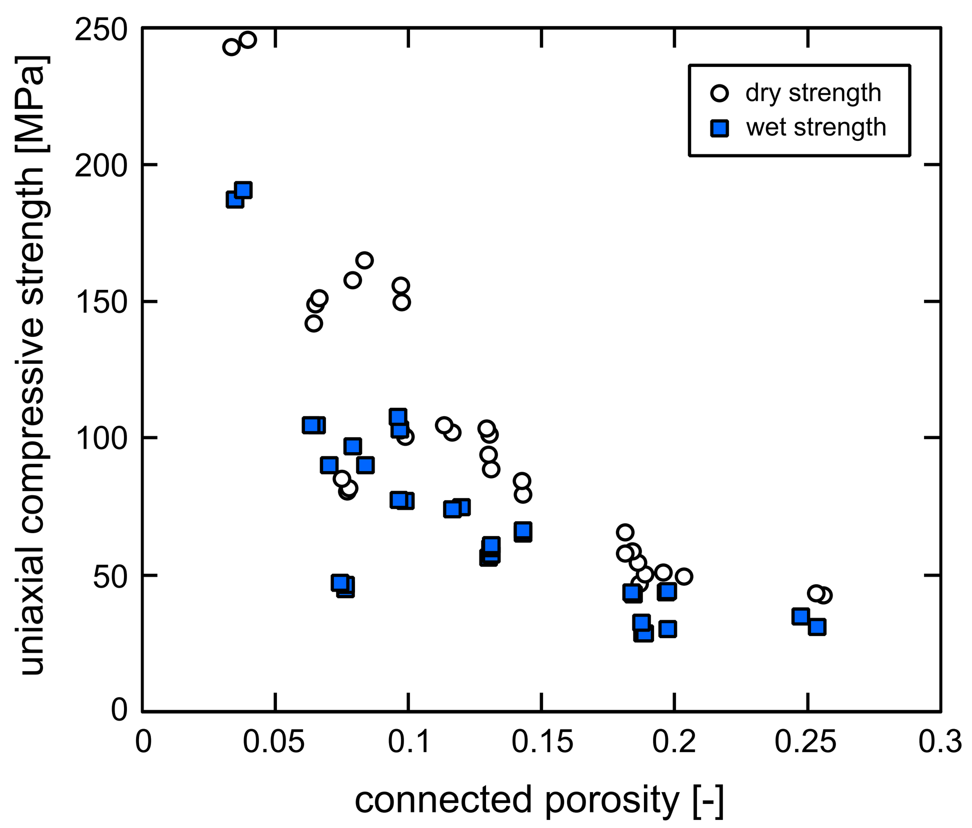
Samples were either deformed "oven-dry" or vacuum-saturated with deionised water and deformed inside a water bath ("wet").

Measurements of displacement and load were monitored by an LVDT and a load cell, respectively.

Displacement and load were converted to strain and stress using the sample dimensions.



4 Experimental results

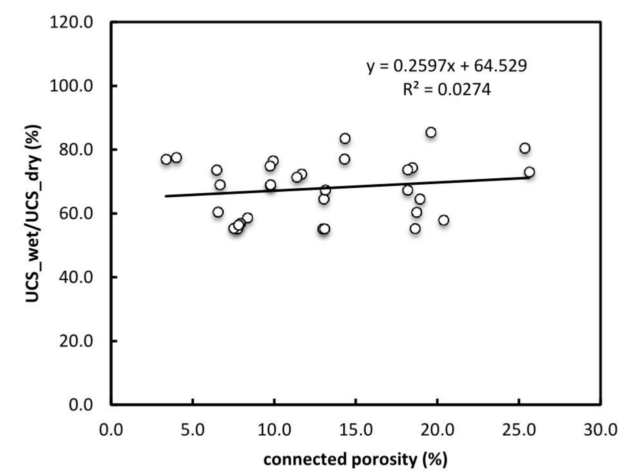


Our results show that all the sandstones from exploration borehole EPS-1 are much weaker when water-saturated.

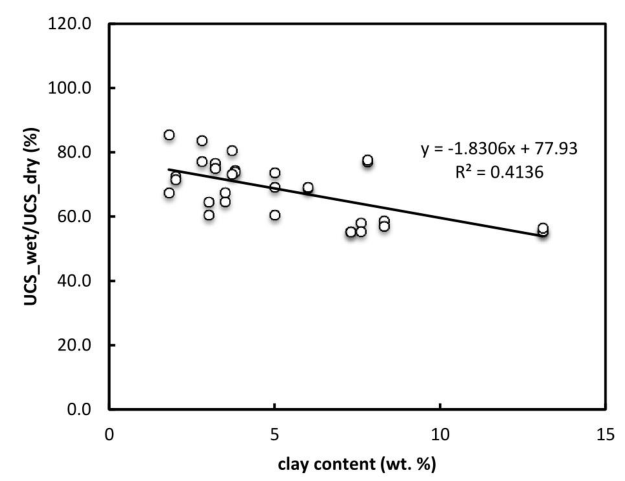
The ratio of wet to dry uniaxial compressive strength—a common metric for water weakening in rocks—is found to be between 0.55 and 0.8.

6 Discussion

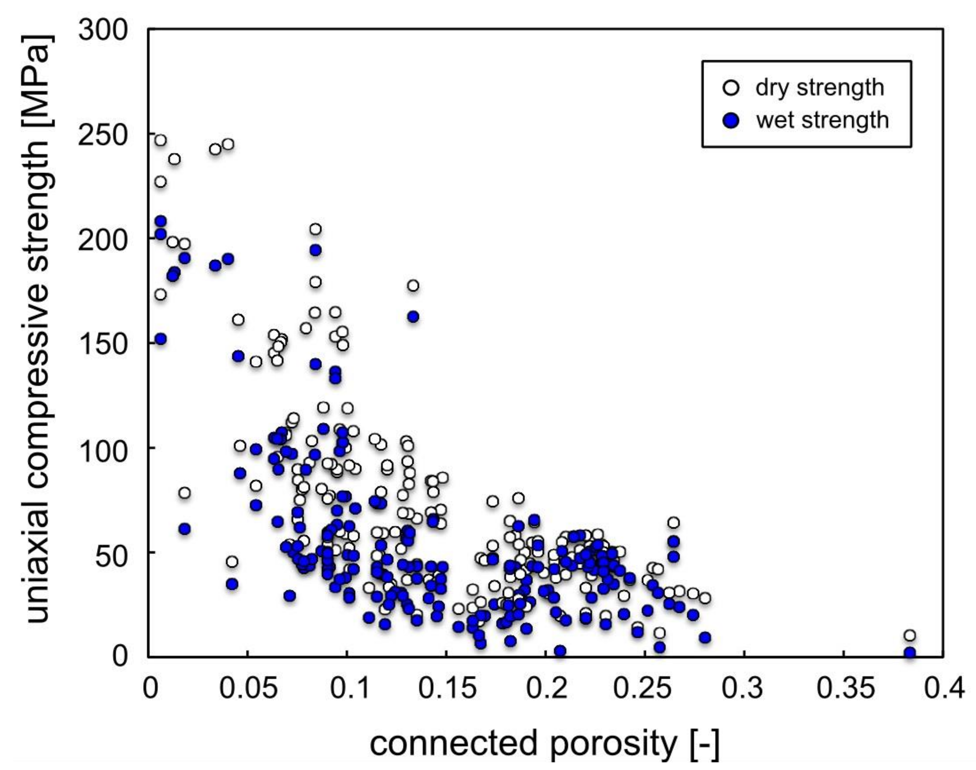
To better understand the water-weakening process in the EPS-1 sandstones, we plot the ratio of wet and dry strength as a function of porosity and clay content (graphs on the right).

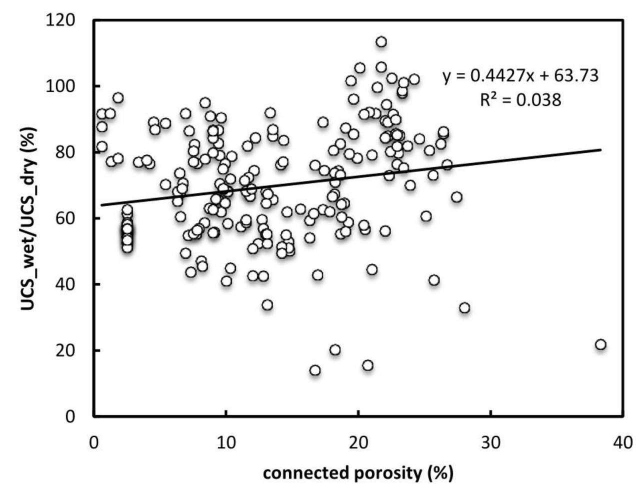


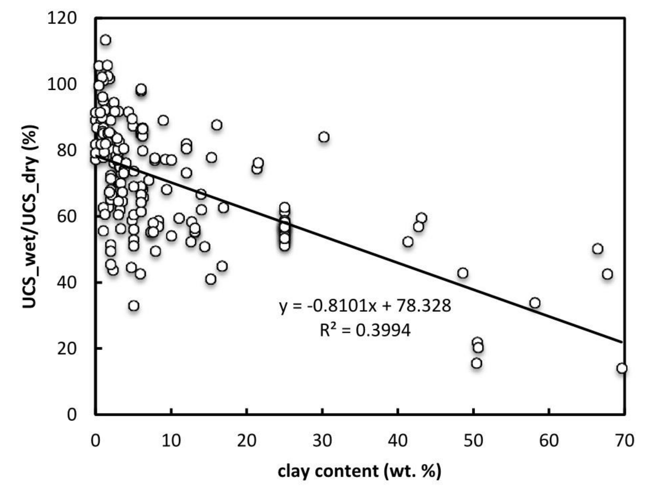
We find that water weakening does not depend on connected porosity, but does correlate with clay content (R3 illite-smectite and muscovite).



Ratios of wet to dry uniaxial compressive strength are lower for rocks containing high clay contents, and vice versa.

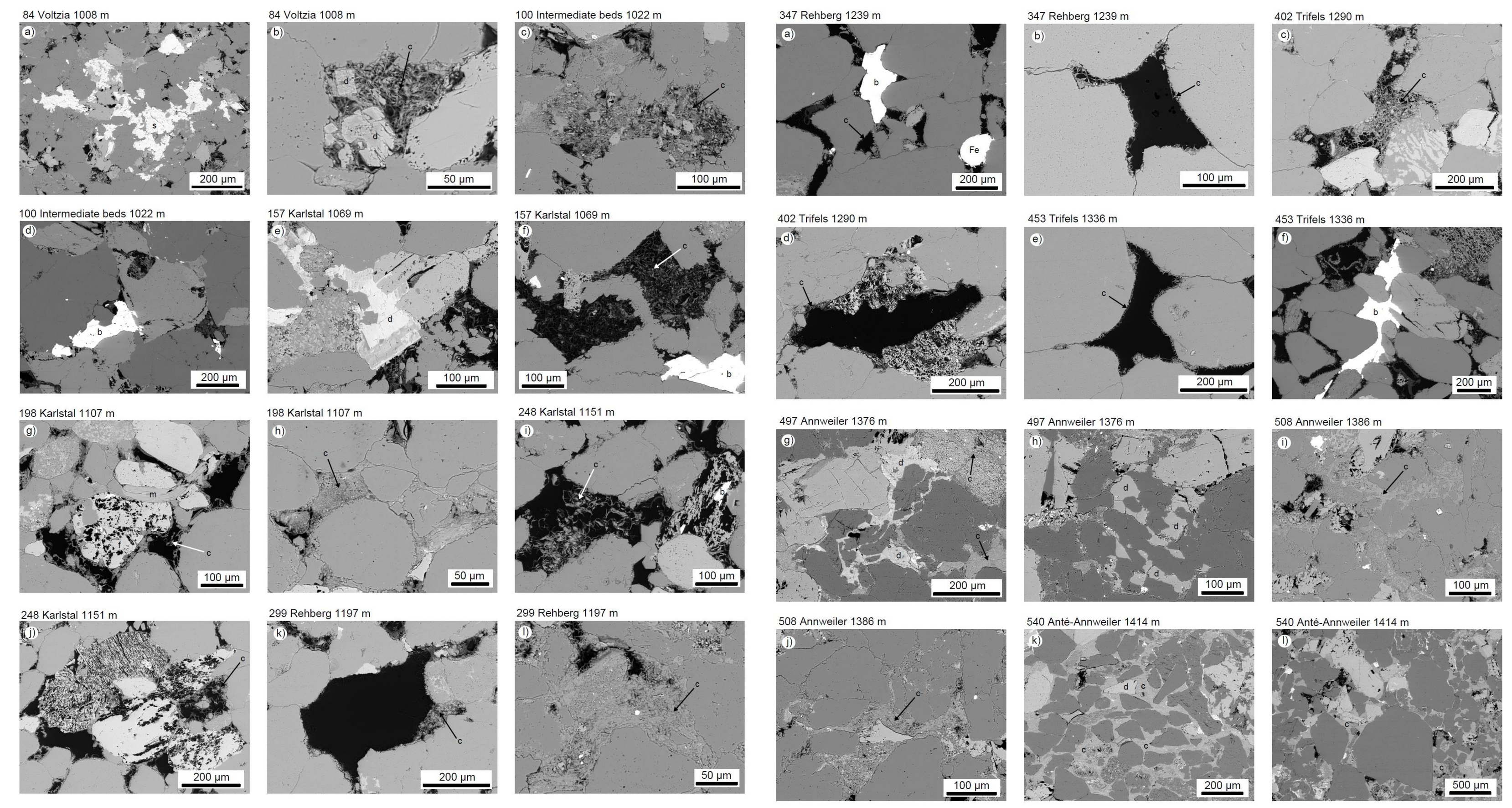






Our data are in agreement with those previously published for sandstones (over 200 datapoints from more than 10 separate studies; see graphs above). These compiled data show that clay content appears to play a signifcant role in the water-weakening of sandstones.

The Buntsandstein samples from EPS-1 contain abundant pore-filling clays due to hydrothermal alteration (see SEM images below).



7 Future work

We will use these laboratory data to provide dry and wet rock-mass (i.e. upscaled) strengths of the Buntsandstein using Geological Strength Index (GSI) assessments of the core and the generalised Hoek-Brown failure criterion (a well-known and widely-used tool in geotechnical engineering).

Our laboratory data suggest that wet rock-mass strengths will be much lower than the dry rock-mass strengths. Since the in-situ rock-mass is saturated with fluid, these data and analyses highlight the need for wet laboratory experiments when providing estimates for the intact and rock-mass strength of the Buntsandstein—an important rock unit for geothermal exploitation in the Upper Rhine Graben—and other geothermal sites worldwide.